Naval Research Laboratory
Washington, DC 20375-5320

NRL/FR/7140--98-9872

LOCUTUS 2.0: Advanced U.S. Navy Capability to Process METOC Data from NOAA TIROS DCS-capable Platforms

WILLIAM G. POPOVICH
ROBERT E. DELGADO

Acoustics Simulation and Tactics Branch
Acoustics Division

DAVID MCCAFFREY

Planning Systems Incorporated
Slidell, Louisiana

DAVID SALLIS

Analysis and Technology, Incorporated
Bay St. Louis, Mississippi

March 31, 1998

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)

2. REPORT DATE

March 31, 1998

3. REPORT TYPE AND DATES COVERED

Final

4. TITLE AND SUBTITLE

LOCUTUS 2.0: Advanced U.S. Navy Capability to Process METOC Data from NOAA TIROS DCS-capable Platforms

5. FUNDING NUMBERS

64218N

6. AUTHOR(S)

William G. Popovich, Robert E. Delgado, David McCaffrey,* and David Sallis**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/FR/7140--98-9872

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Commander, Space and Naval Warfare Systems Command
METOC Systems Program Office, PMW185
San Diego, CA 92110-3127

The Oceanographer of the Navy
(CNO-N096)
United States Naval Observatory
Washington, DC 20392-5421

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Planning Systems, Inc.
**Analysis and Technology, Inc.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

Since January 1992, scientists from the Acoustics Division of the Naval Research Laboratory have made great advances in the ability to receive, decode, and display METOC data using NOAA TIROS DCS-capable satellite receiving stations. Using in-house or commercial off-the-shelf equipment and government-furnished LOCUTUS 2.0 software, it is now possible to receive, decode, display, and report METOC data from a wide variety of DCS-capable transmitters, including U.S. Navy fixed and drifting oceanographic buoys, automatic weather observation stations, and high-tech experimental buoys. Complete postprocessing of all sensor data and accurate range-rate position fixing of drifting buoys are performed routinely and automatically, completely independent of external data processing. Local satellite "footprint" data reception is accomplished using several Navy satellite receiver systems, both VHF and S-band. Worldwide transmitter coverage from the TIROS GAC-1A telemetry link is also routinely provided. Project sponsorship and resources are provided by the NRL Tactical Oceanography Warfare Support program office and the SPAWAR METOC Systems program office.

14. SUBJECT TERMS

Sonobuoy	Antisubmarine warfare	Satellite
Oceanography	TESS 3	Telemetry
Meteorology	Acoustics	

15. NUMBER OF PAGES

26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

CONTENTS

Preceding Page Blank

LOCUTUS 2.0: ADVANCED U.S. NAVY CAPABILITY TO PROCESS METOC DATA FROM NOAA TIROS DCS-CAPABLE PLATFORMS

LOCUTUS DESCRIPTION

LOCUTUS 2.0 is software that receives, decodes, and displays environmental data using selected meteorological and oceanographic (METOC) satellite receiver systems. Developed at the Naval Research Laboratory's facility at Stennis Space Center, Bay St. Louis, Mississippi, LOCUTUS is written in the C programming language with X-Windows/Motif style graphics for the UNIX operating system. The software enables users of these selected systems to process digital data from UHF transmitter devices compatible with the data collection system (DCS) transceiver aboard the National Oceanic and Atmospheric Administration's (NOAA) TIROS satellite. These data may be environmental, METOC, or diagnostic, depending on the construction of the device. The devices are called platform transmit terminals (PTT) and are designed and operated within specifications agreed upon by international agreement, with the major parties being the United States (via NOAA) and France (via Le Centre National D'Etudes Spatiales (CNES)). This agreement stipulates a standard digital data format for all PTTs and provides guidelines for receiving and processing data. PTT users, who have no in-house satellite receiving equipment capable of direct reception and processing of TIROS DCS telemetry, can purchase custom data processing, PTT location service, and data delivery from Service ARGOS, Inc. By the same agreement, all users of DCS-compatible PTTs must pay a service fee to Service ARGOS, Inc. for the right to be assigned DCS identification numbers. The agreement allows for control of the volume of PTT transmissions through TIROS satellites, preventing saturation of the DCS transceivers.

A thriving industry has evolved in the manufacture of a huge variety of waterborne buoys, current/tide meters, animal trackers, weather stations, and similar devices incorporating passive measurement equipment and the standard TIROS DCS-compatible PTT. The allotment and arrangement of the devices' sensors and internal diagnostic meters within a 256-bit DCS uplink *message* has been termed the *format* or the *technical file* of the device. The technical specification of the DCS signal and DCS word has been an international standard for decades and is listed in publications both from NOAA and Service ARGOS, Inc. [1]. The important features of the specification are the frequency (401.65 ± 0.4 MHz short term), data rate (400 bps), polarization (linear and right-circular), carrier modulation (phased-shift keyed), data modulation (split phase-Manchester code), and power requirements of the signal plus the length, arrangement, and stop/start bit patterns of the uplink word [2]. Having satisfied these PTT parameters, the designer of an environmental or METOC measuring device incorporating a DCS-capable PTT to telemeter the data must arrange external sensors and internal diagnostic equipment in the device to assure mechanical and electronic compatibility with the PTT. The limitation imposed by the standard of 32 eight-bit words of a DCS message is the paramount limitation in the design and construction of a PTT-bearing instrument. PTT circuitry can be tightly manufactured to occupy a volume of just a few cubic inches. This miniaturization allows great flexibility in the design and manufacture of measurement devices incorporating a PTT to telemeter sensed data to TIROS.

Manuscript approved November 17, 1997.

Since the 1970s, several commercial TIROS satellite receiving systems have been successfully manufactured and marketed in the Western world, with the capability to independently process, Earth locate, and deliver PTT data relayed through the TIROS DCS transceiver. Some systems receive DCS data from the TIROS VHF double sideband digital downlink; others strip out the DCS data from the TIROS high resolution picture transmission (HRPT) S-band telemetry stream. All of these systems deliver the PTT data in alphanumeric ASCII form with little or no graphics enhancement. No commercial system delivers capability to process and display PTT data from the taped-data orbital dump from the TIROS global area coverage (GAC-1A) S-band downlink signal. LOCUTUS 2.0 was developed in response to demand from the Navy for real-time, at-sea reception of METOC data from Navy-operated fixed and drifting PTTs for operational tactical use. Over the course of four years of intense engineering development, graphic presentation of METOC data from PTTs using LOCUTUS software was accomplished on a collection of government and commercial TIROS satellite receiver systems. A list of LOCUTUS-capable platforms follows:

- VHF FG-7104 Local User Terminal (LUT)
  Naval METOC facilities worldwide where TESS-3/SMQ-11 capability is not yet available; U.S. Naval Oceanographic Office (NAVOCEANO), National Data Buoy Center (NDBC, a NOAA command), both at Stennis Space Center, Bay St. Louis, MS

- U.S. Navy TESS-3/SMQ-11 SHF METOC Satellite Receiving System
  Naval METOC Command activities worldwide, U.S. Navy major combatant air-capable ships

- TELONICS T-RIS SHF Satellite Receiving System
  Naval Pacific METOC Center West/Joint Typhoon Warning Center, Guam; NAVOCEANO

- GLOBAL Imaging Inc., HIPS SHF Satellite Receiving System
  National Hurricane Center (NHC, NOAA), Miami, FL

- U.S. Navy TIROS GAC-1A DOMSAT Feed System
  NAVOCEANO, U.S. Naval Ice Center (NAVICEN), Suitland, MD

- Satellite Data Receiving and Processing System (SDRPS)
  Stennis Space Center, Bay St. Louis, MS

Figure 1 is a system diagram of LOCUTUS communications connectivity.

LOCUTUS PROJECT HISTORY

The origins of the effort to achieve TIROS DCS-capable platforms began with the Navy's requirement for new and improved tactical sonobuoys. The NRL Tactical Oceanographic Warfare Support (TOWS) program office began the Drifting Buoy Engineering Enhancement Project in the mid 1980s to improve the capability of the common eight-hour sonobuoy in the fleet inventory and the free-drifting sonobuoys that were state of the art at the time. The main effort was to expand the capability of A-sized, long-life meteorological drifters, which came with a standard *met* package of surface air pressure, sea surface temperature, and surface air temperature and to introduce these upgraded drifters

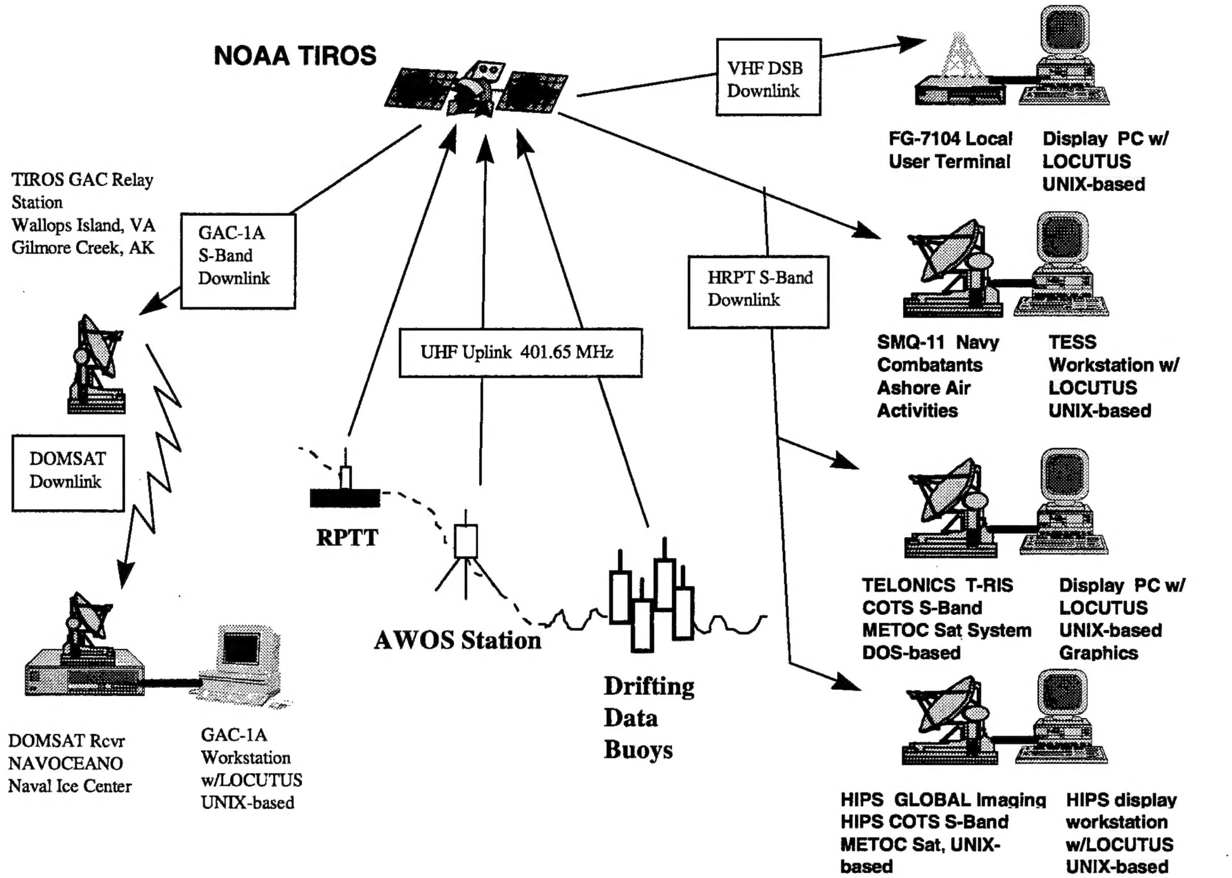


Fig. 1 — LOCUTUS connectivity

into fleet inventories to provide long-term METOC data collection capability unavailable from eight-hour fleet sonobuoys. The newly designed drifting buoy was given the designation AN/WSQ-6, with variations XAN-1 through XAN-4 that included the addition of thermistor chains and submerged hydrophones. The extensive WSQ-6 development project is described in Ref. [3]. The baseline design of this series of buoys was derived from the DCS-compatible compact meteorological and oceanographic drifter (CMOD) buoy developed by METOCEAN Data Systems of Halifax, Canada, and deployed in large numbers for the U.S. Navy by NAVOCEANO. This effort was initiated with direction in the form of fleet requirements from both the Office of the Oceanographer of the Navy (CNO-N096) and the Commander, U.S. Naval Meteorology and Oceanography Command (CNMOC). Improvements were also sought in deployability (especially P-3, S-3, and LAMPS launch capability), longevity, and sensor capability. As new buoys with thermistor tails, submerged hydrophones, optical sensors, and wave sensors were being tested, the lack of graphic data depiction was a severe handicap in the demonstration and evaluation (DEM/VAL) stage of buoy development. The capability to produce an in-house automatic graphical data display was immediately required to help engineers construct new state-of-the-art buoys.

With the increasing importance of littoral warfare and the sharp reduction in the Soviet submarine threat after the end of the Cold War, CNO-N096 and CNMOC became interested in METOC data from critical inshore locations. To remotely and routinely collect these data, CNMOC substantially invested in a

capability called the Automated Weather Observation Station (AWOS). Several commercial versions of AWOS equipment were tested and deployed in tactically high-interest areas. The AWOS units procured for long-term use were TIROS DCS-capable platforms, transmitting METOC data in exactly the same manner as drifting buoys. AWOS stations have become a mainstay in the CNMOC inventory and are an important METOC data source in hot spots like Bosnia and Korea.

Of the myriad METOC instruments in manufacture within the industrialized world that incorporate TIROS DCS-capable PTTs for data telemetry, several varieties have been of interest and have been frequently used by the Drifting Buoy Engineering Enhancement Project. The most important has been the AN/WSQ-6 series of buoys, built specifically for the project. Later variants of the WSQ-6 incorporated intricate wave, tide, and water clarity measuring devices. Other platforms of interest have included METOC and wind-speed and direction buoys built for NOAA-NDBC, current-tracking *Davis-drifters* used by major colleges and oceanographic institutions, and the CNMOC, AWOS unit. At the inception of the Drifting Buoy Engineering Enhancement Project, all data gleaned from NRL-built drifting buoys were purchased from Service ARGOS, Inc. in the form of floppy disks sent by mail or files downloaded from TYMNET subscription using modem communications. Delivery of ARGOS environmental data in real time to warships at sea was found to be inherently impracticable due to data processing delays and the built-in time delay of the GAC-1A TIROS DCS taped-data relay system on a per-orbit basis. ARGOS time delays hampered on-scene buoy engineering evaluations as well. The Navy became acutely interested in the ability to receive its own drifting buoy data in real time at sea with operational fleet units as well as ashore for engineering purposes.

Program managers at the NRL TOWS program office and the METOC Systems Section of the Space and Naval Warfare Systems Command (SPAWAR PMW-185) consulted during the spring of 1991 and decided that the ability to process and deliver METOC data from TIROS DCS-capable drifting buoys and AWOS stations should become a mission capability of the Tactical Environmental Support System (TESS-3). The TESS-3 system, using the AN/SMQ-11 satellite receiving antenna, was and continues to be the Navy's flagship, real-time, METOC data receiving platform for air-capable combatant ships and major ashore aviation activities. A new software module, with the ability to receive, decode, display, and deliver METOC data from drifting buoys and AWOS would be designed and integrated with the extensive TESS-3 METOC support software already. Design work began in earnest in the summer of 1992 by members of the Simulation and Tactics Branch of NRL's Acoustics Division LOCUTUS Team (authors of this report).

TESS-3 INTEGRATION

Initial engineering evaluation of the TESS-3/SMQ-11 revealed that the SMQ-11 TIROS-receiving software module, developed by Lockheed and MacDonnel-Detwiler Corporation, was already capable of delivering TIROS HRPT imagery and unprocessed binary TIROS Information Package (TIP) data with every TIROS pass. This module stripped out the binary TIP file from the HRPT telemetry stream and wrote it to a flat file on the TESS-3 computer disk drive. With no processing software to manipulate the TIP file, the TIROS-receiving software module ignored the TIP file and overwrote it with each subsequent TIROS pass.

TIP file decoding software for a similar TIROS HRPT receiver antenna system was obtained from scientists at Science Systems and Applications, Inc. (SSAI) in Lanham, Maryland. This software was funded and sanctioned by the International Data Systems Office of the NASA Goddard Space Flight Center in Greenbelt, Maryland. The SSAI TIROS-HRPT downloading software functioned as a template to engineer a similar software module for the TESS-3/SMQ-11 system. Included was a well documented

TIP file DCS frame decoder and a range-rate/Doppler-shift positioning algorithm for DCS PTT. The module was written in FORTRAN 66 for a VAX/VMS-based HRPT S-band antenna system [4]. This code was completely rewritten into the C programming language in a process lasting several months. The module was then fitted with an elaborate graphical user interface (GUI) written in the X-Windows/Motif graphics environment, in accordance with TESS-3 software standards promulgated by SPAWAR, NRL, and NAVOCEANO.

Several end-to-end tests were conducted in the spring of 1993 at NRL's detachment in Monterey, CA, using the TESS-3/SMQ-11 system belonging to NRL's Tactical Systems Section. Further tests were conducted remotely, using Internet connectivity between the West Coast and Gulf Coast NRL detachments. By the spring of 1994, drifting buoy METOC data were being proficiently processed and displayed by the new LOCUTUS software module, loaded on a CONCURRENT 9000 computer, the standard host at the time for the TESS remote workstation (TRWS). In the fall of 1995, the Tactical Environmental Database Subsystem (TEDS) *hooks* were developed and incorporated into the LOCUTUS software module. When LOCUTUS and TEDS are resident together on the TESS-3 computer, the hooks cause LOCUTUS to automatically write METOC data into appropriate TEDS database fields immediately upon reception of TIROS DCS data from the SMQ-11. The METOC buoy data are later processed with METOC data collected by other TESS-3 modules to ground truth and modify remotely sensed atmospheric gridded field observations.

Naval communication of buoy data has been an important issue from the beginning of the LOCUTUS project. To comply with the requirement for METOC buoy data to be freely exchanged between units in a naval battle group, an automatic over-the-horizon-targeting GOLD (OTH-T GOLD or OTG) message formatter was designed and incorporated into LOCUTUS. The LOCUTUS-generated OTG message complies with the latest OTG instruction promulgated by the Naval Center for Tactical Systems Interoperability, in San Diego, CA. Transmission of LOCUTUS-received buoy data with METOC interests worldwide was addressed by the development of the World Meteorological Organization (WMO) code message formatter. LOCUTUS automatically produces *BUOY* messages (formerly *DRIFTER*) compatible with the latest WMO message code standards. Both formatters produce ASCII flat-file messages for floppy disk transfer to communications servers. At naval METOC facilities with TESS-3 capability, LOCUTUS OTG messages can be transferred to the Automatic Digital Network (AUTODIN) or the Officer in Tactical Command Information Exchange System (OTCIXS) servers for further transmission as naval messages. Automatic transmission of LOCUTUS OTG messages via naval communications channels using TESS is being developed. WMO BUOY messages originating from the GAC-1A DOMSAT feed at NAVOCEANO are routinely transmitted worldwide via the Global Telecommunications Service (GTS). Figure 2 shows OTG and BUOY sample messages generated by LOCUTUS.

The first LOCUTUS operations using an operational TESS-3/SMQ-11 system with a true TRWS occurred at the Naval European METOC Detachment, Naples, Italy, during the SHAREM 117 fleet exercise in June 1996. LOCUTUS data from the exercise are displayed on page 14 of this report.

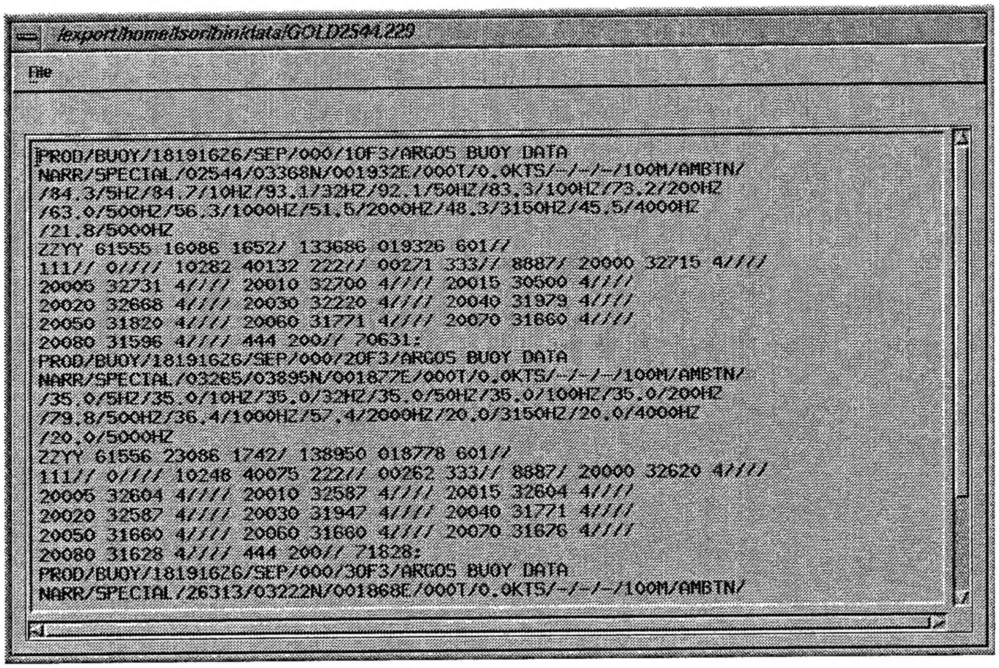


Fig. 2 — Sample OTG message

LOCUTUS SPREAD TO COTS METOC SATELLITE RECEIVING SYSTEMS

Along with efforts to develop TIROS DCS transmitter data processing capability for the TESS-3/SMQ-11 system, parallel endeavors were made to enhance the same capabilities within several commercial-off-the-shelf (COTS) TIROS satellite receiver sets with naval or maritime METOC applications.

VHF Local User Terminal (NAVOCEANO and NDBC)

Beginning in the spring of 1993, the rapidly maturing software module being developed for the TESS-3 system was seen to be sufficiently versatile to be used to upgrade the FG-7104 VHF local user terminal (LUT). The LUT had been in use for a decade by drifting buoy personnel of NAOCEANO's Oceanographic Processing Division to deliver real-time oceanographic buoy data to some of the Navy's most remote METOC outposts that had no other method to obtain TIROS DCS transmitter data. Personnel at naval METOC activities at Guam, Bermuda, Misawa (Japan), and Keflavik (Iceland) all used the LUT with its excellent VHF TIP data receiving capability but also with its primitive DOS character-based operating software. Encountering huge increases in METOC buoy data volume after 1990, the LUTs became unacceptably difficult to operate and deficient in buoy data storage capacity. The LUT software was also devoid of geographic or temporal graphics of buoy data, highly desired by forecasting personnel.

A joint engineering effort was launched between NAVOCEANO and NRL to develop a LUT upgrade incorporating the same computational and graphics software employed in the TESS-3 project. The decision was made to altogether abandon the DOS-based, PASCAL-encoded LUT software for Navy LUT applications. In engineering the software upgrade for the FG-7104, it was decided to use the existing VHF receiver portion of the LUT, design and build a new TIP frame synchronizer circuit card, and control this card and the receiver with the UNIX-based X-Windows/Motif NRL software in development for TESS-3.

The software module was adapted for IBM-compatible PCs of 486 speed or higher by equipping the PCs with the SCO UNIX 3.0 operating system and writing a UNIX device driver to operate the TIP frame synchronizer card. This card, built with assistance from NRL's Remote Sensing Branch, Stennis Space Center, Mississippi, was designed to fit the ISA slot of an IBM-compatible computer and to replace the proprietary, enclosed TIP frame synchronizer circuit board stack internal to the LUT receiver. This arrangement allowed for the raw TIP signal from the receiver to be tapped via serial communications connection to the ISA frame synchronizer card, which could operate satisfactorily in virtually any 386 or faster PC capable of running SCO UNIX 3.0 and X-Windows applications. With close cooperation between the FG-7104 designer, NRL, and NAVOCEANO, a fully functioning upgraded LUT was operational in the fall of 1994, after about one year's work. The upgrade of LUT hardware and software add-on equipment suggested the title of LUT Upgrade System, from which the acronym LOCUTUS was derived and soon adopted as the catchy name of the whole software module. LOCUTUS-equipped LUTs have been installed in high-profile naval METOC activities in Guam, Bahrain, Japan, and Sicily, providing a temporary TIROS DCS processing capability until the permanent installation of LOCUTUS-capable TESS-3/SMQ-11 upgrades.

TELONICS T-RIS SHF Satellite Receiving System

Eight of these 1.2-m dish systems were procured by NAVOCEANO's Oceanographic Processing Division in the summer of 1994 to be deployed ashore at METOC installations to replace LUTs that were experiencing performance degradation due to excessive local VHF interference. A T-RIS-compatible LOCUTUS program was developed by the NRL LOCUTUS Team to run on a UNIX-based 486-PC alongside the DOS-based T-RIS operations computer. The system was tested and perfected at NAVOCEANO and successfully deployed at the Naval Pacific METOC Center/Joint Typhoon Warning Center in Guam during the summer of 1996. Dramatic METOC data collected from drifting buoys overrun by a typhoon are described on pages 17 and 18 of this report.

HRPT Image Processing System (GLOBAL Imaging, Inc.) at National Hurricane Center

During the summer of 1994, a LOCUTUS-capable VHF LUT was installed on the thirteenth-floor roof of the National Hurricane Center (NHC) headquarters in Coral Gables, Florida. The installation allowed hurricane forecasters to use real-time METOC buoy data in conjunction with a government-wide meteorological project called Air-Drop Deployment of Buoys in the Path of a Tropical Cyclone. No acceptable storms formed during the 1994 hurricane season, and the LUT was removed during the spring of 1995. The project was postponed until the 1995 season, and NHC moved to new spaces near Florida International University in Miami. To enhance its remote sensing capability for daily METOC operations, NHC procured and installed a sophisticated new METOC SAT dish receiving system called HRPT Imagery Processing System (HIPS), manufactured by GLOBAL Imaging, Inc.. The NRL LOCUTUS team consulted with GLOBAL Imaging and engineered a LOCUTUS software module compatible with HIPS. The successful operation LOCUTUS software on the HIPS system and the timely delivery of METOC and oceanographic drifting buoy data to NHC forecasters during two hurricanes in the summer of 1995 are described in detail on page 16 of this report.

U.S. Navy Satellite Data Receiving and Processing System (SDRPS)

This multidish METOC SAT receiving and display system, built around a TERASCAN satellite receiver, has been in use for years at the Remote Sensing Branch at NRL's Stennis Space Center, Mississippi. In addition to receiving imagery from a variety of METOC satellites, SDRPS is capable of

receiving TIROS DCS data from both the global area coverage (GAC)-1A DOMSAT feed and the HRPT S-band footprint downlink [5]. In the fall of 1994, a LOCUTUS module was engineered and perfected for SDRPS, becoming operational after about six months of development. Since then, the SDRPS system has been used by the LOCUTUS team both to receive local HRPT- and local area coverage (LAC)-delivered TIP data and as a GAC-1A backup to the systems at NAVOCEANO and the Naval Ice Center, Suitland, Maryland.

DECODING OF DCS-CAPABLE TRANSMITTER TECHNICAL FILES BY LOCUTUS

The heart of the LOCUTUS software package is the program module that loads, decodes, and manipulates the TIP file received from a TIROS Satellite receiving station. This module, hereafter called the TIP Decoder, parses the binary TIP file and separates its main components for further processing, as suggested by the TIP file specification described in two NOAA publications [6,7]. The 104-word TIP frames are parsed, and the words containing DCS data from PTTs are separated and concatenated into a series of DCS messages, each representing a single transmission from a PTT. The TIROS stratospheric, microwave, and space sounder data contained within the TIP file alongside the DCS data are ignored. The S-band METOC SAT systems used in the LOCUTUS project all deliver a complete binary TIP file to disk using indigenous software, either as a separate file or as part of the HRPT picture file. LOCUTUS is able to read this TIP data with every TIROS pass and perform its load, decode, and manipulate functions independently. In the case of the VHF LUT, the TIP file is received one frame at a time by using the NRL-produced frame synchronizer PC card and accompanying SCO UNIX device driver.

Each DCS message consists of the PTT ID number, the time the data were received by the satellite, the Doppler shift measured by the satellite, and up to 32 bytes of data transmitted by the PTT. The TIP processing module decodes the ID number, time stamp, and Doppler measurements and checks them for transmission error. The PTT ID number is compared against a list of known ID numbers. If it is found, the DCS message is saved for further processing. Otherwise, the DCS message is discarded.

LOCUTUS GRAPHICAL USER INTERFACE

The LOCUTUS GUI is a one-display data management and device operation system compatible with the UNIX operating system in an X-Windows environment. It was written using the Motif toolkit and was designed to meet military software coding specifications for TESS-3 candidate software modules. LOCUTUS versions have been developed to work with the SunOS 4.1, HP-UX 9.05, Silicon Graphics IRIX 5.3, Concurrent RTU 6.2, and SCO Unix 3.0 operating systems.

The main window of the interface is organized around an interactive geographic location display that allows the user to visualize the current and past geographical locations of drifting buoys. Several map projections and other configuration options are available to maximize the utility of the map display. Other functions that control the remaining aspects of TIP file postprocessing, software configuration, and product generation are organized into separate dialogs which are available from the interface's menu bar.

The TIP file decoding scheme is built around a PTT technical file database and an active transmitter database. Management of these files has been a tedious manual task using old LUT character-based software. Two custom dialogs (point-and-click graphics) have been designed to simplify this task. The first dialog (Fig. 3) is known as the Active Transmitters List Editor and is used to manage the database of

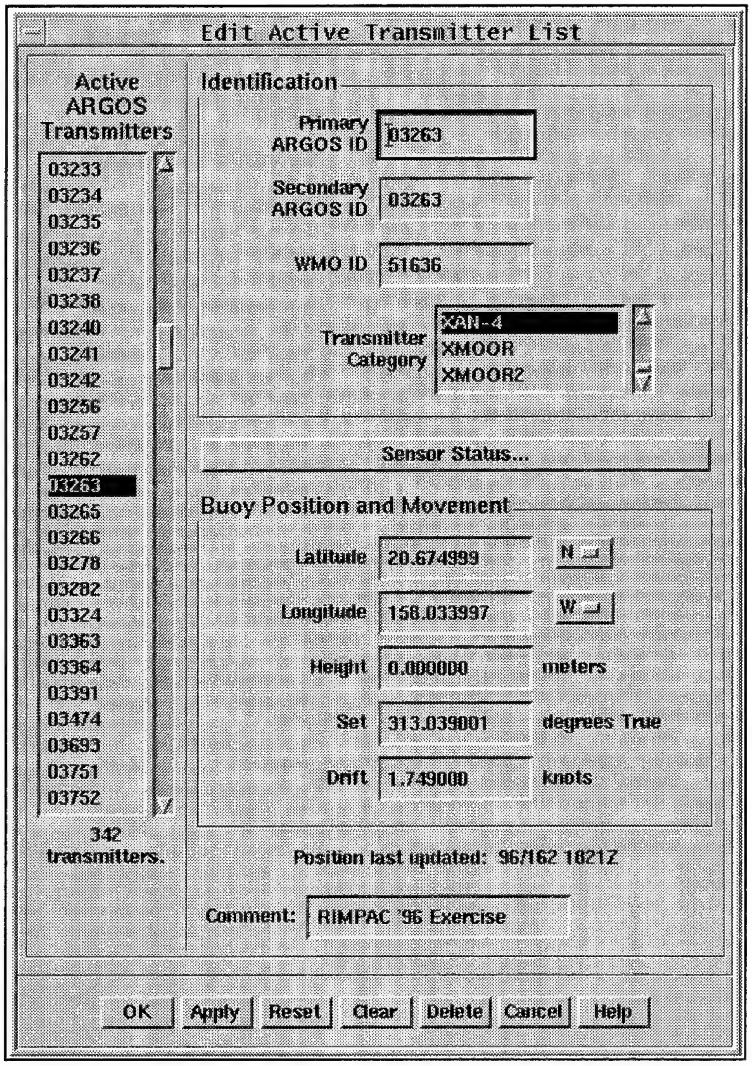


Fig. 3 — Active Transmitters List Editor

PTT ID numbers. With this dialog, the user may create, modify, and delete records that contain information pertaining to individual PTTs. Each PTT record contains the ARGOS and WMO ID numbers, its technical file (called *category format* on the menu bar), sensor status, geodetic height, drift direction and speed (nautically, *set* and *drift*), and the last known geographic location.

The next dialog (Fig. 4) is called the Category Format Editor and is used to manage the database PTT technical files. The dialog is organized around a spreadsheetlike object, which is used to edit a matrix of environmental sensor names and decoding coefficients. Use of this dialog allows the user to easily modify the contents of the database. The user also can view the entire contents of the technical file at a glance.

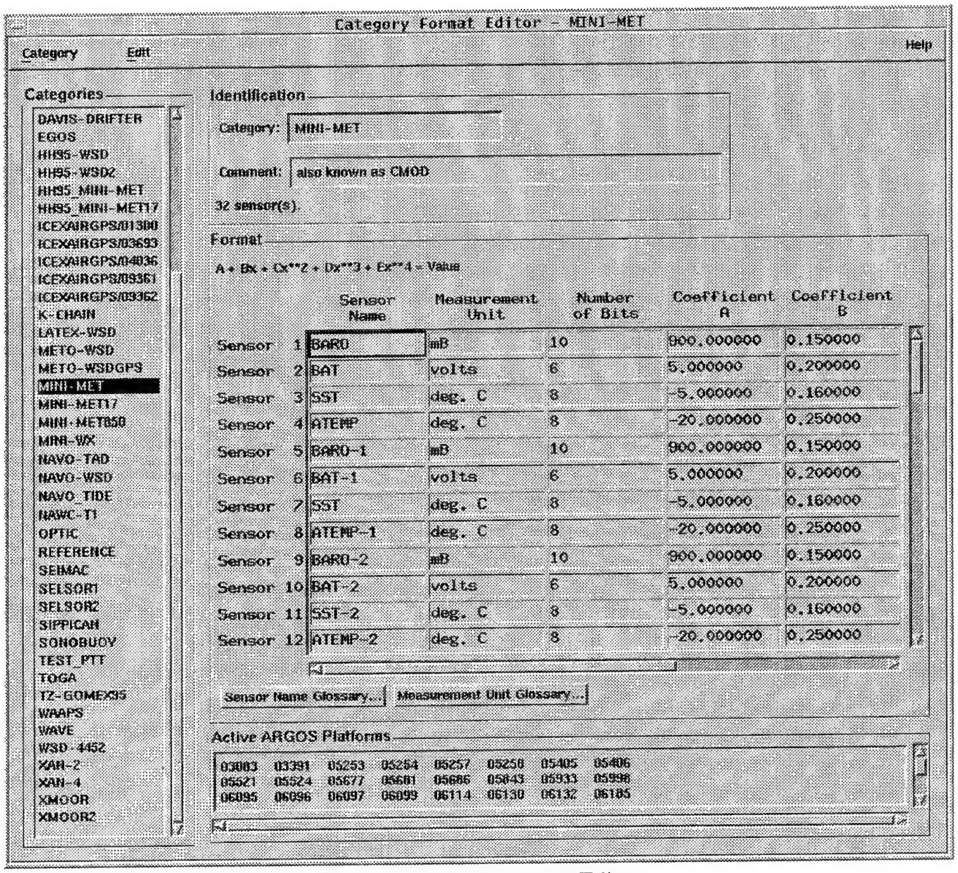


Fig. 4 — Category Format Editor

Software Products

A collection of time-series fixed graphic displays is used to depict multiday trends of meteorological and oceanographic parameters of interest to the tactical commander. Meteorological data (barometric pressure, air temperature, sea surface temperature, wind speed, direction) and oceanographic data (water clarity, ambient noise, thermal structure, wave character) are rendered into continuous multiday time-line plots. The meteorological data may also be presented on the geographic location display in the form of a standard synoptic station model displayed over the buoy's latest position. Oceanographic parameters are each depicted in separate graphic products. Examples of LOCUTUS graphics are shown throughout the remainder of this report. An exhaustive description of all LOCUTUS features is too lengthy for this report, so only the most important features have been described. A complete LOCUTUS Users Manual and detailed MIL 2167-A documentation for military software requirements pertaining to the TESS-3 system [8] have been produced.

WORLDWIDE TIROS GAC/LAC CAPABILITY

LOCUTUS decoder and graphics software has been adapted to process GAC- and LAC-taped data from TIROS. Environmental data from CNMOC-NAVOCEANO operational drifting buoys and NRL experimental buoys are routinely processed by LOCUTUS software resident on an HP-J210 computer at NAVOCEANO's Warfighting Support Center (NAVOCEANO WSC). Taped GAC-1A data are received

at NOAA Command and Data Acquisition (CDA) ground stations at Fairbanks, Alaska, and Wallops Island, Virginia, and are relayed to the NAVOCEANO WSC through the Domestic Communication Satellite (DOMSAT). Raw TIP data from the GAC files are automatically downloaded, decoded, and stored by LOCUTUS. Archived data are stored for one year. All data can be examined by LOCUTUS graphics on demand. Duplicate capability is available at the Naval Ice Center, Suitland, Maryland, for purposes of backup and redundancy.

POSITIONING ALGORITHM

Within the LOCUTUS software, positioning of TIROS DCS-capable transmitters is accomplished through the use of a carrier frequency range-rate (Doppler shift) positioning algorithm. This algorithm is adapted from software originally developed for NASA in the 1960s and 1970s, in which an orbital propagation model and a range-rate model were merged into a ground transmitter positioning program. The algorithm uses the Brouwer-Lyddane orbital propagation model with special capability to effect orbital correction by means of fixed TIROS DCS-capable reference ground stations or reference platform transmitter terminals (RPTTs). RPTTs are the key to accurate range-rate calculation of the positions of moving PTTs; those RPTTs belonging to the U.S. Navy and Service ARGOS, Inc. are professionally benchmarked to submeter accuracy. RPTT Doppler shift measurements are used to correct the position of satellite orbits whose position was initially calculated from ephemeris orbital elements. Ephemeris elements are updated by using one or more RPTTs to render corrected orbits.

A geocentric position and speed of the satellite are calculated for each RPTT transmission using the Brouwer-Lyddane orbital model. The ideal Doppler shift is calculated for each RPTT transmission by using the distance from the RPTT to the satellite, the speed of the satellite, and the transmitter carrier frequency. Next, a least-squares fit is performed between the ideal Doppler shift and the Doppler measured by the satellite. These steps are repeated iteratively until the difference between the measured and calculated RPTT Doppler shifts (the residual) is minimized to effectively zero. A corrected satellite orbit is calculated for each RPTT received by the satellite during one pass. These orbits are used to calculate the location of the other transmitters received during the pass. The same iterative Doppler residual technique is repeated for every non-RPTT ARGOS transmitter detected in the footprint of the satellite pass. A calculated position is delivered for each non-RPTT ARGOS transmitter in the footprint, one per RPTT. The composite RPTT positions are averaged by using a linear weighting function based on the vertical angle between the satellite and each RPTT.

An experimental wind-speed-and-direction GPS drifting buoy was manufactured by CTA Space Systems for demonstration and testing by NAVOCEANO and NRL. The GPS unit installed in the buoy was the Rockwell NavCore V unit, with a published accuracy of 50 to 100 m when using standard positioning service (SPS). In March 1995, an operational test of several of these buoys was conducted in Gulf of Mexico near Pensacola, Florida. Over a 5-day period, buoy positions calculated by the LOCUTUS positioning algorithm were compared with those reported by the NavCore V GPS units aboard each buoy. Table 1 shows the results. *Difference* refers to the Great Circle Path distance between the LOCUTUS and GPS positions. Within five years, all AN/WSQ-6 buoys will be equipped with GPS electronics.

Table 1 — Position Comparison Between Doppler Calculations and GPS Positions

Buoy ID	No. of Positions	Maximum Difference (m)	Minimum Difference (m)	Average Difference (m)
3256	15	957	110	548
3257	20	480	110	258
3258	17	750	220	410
3259	18	600	150	330

SHAREM EXERCISES

Environmental data from U.S. Navy drifting buoys were collected extensively during several U.S. Navy Shipboard Antisubmarine Warfare Readiness and Effectiveness Measurement (SHAREM) exercises in 1995 and 1996. During SHAREM 110, conducted in the Fifth Fleet operating area in March 1995, a total of ten AN/WSQ-6/XAN-2 ambient noise drifting buoys were deployed in the Arabian Gulf and the Gulf of Oman in support of SHAREM antisubmarine warfare (ASW) and undersea warfare (USW) operations. Malfunctions in the SMQ-11 antenna resulted in buoy data that could only be remotely collected using the GAC-1A satcom system at NAVOCEANO. A post-ex METOC and ambient noise analysis of the SHAREM 110 operating area was accomplished. Figure 5 shows seven of the ten XAN-2 buoys deployed in SHAREM 110.

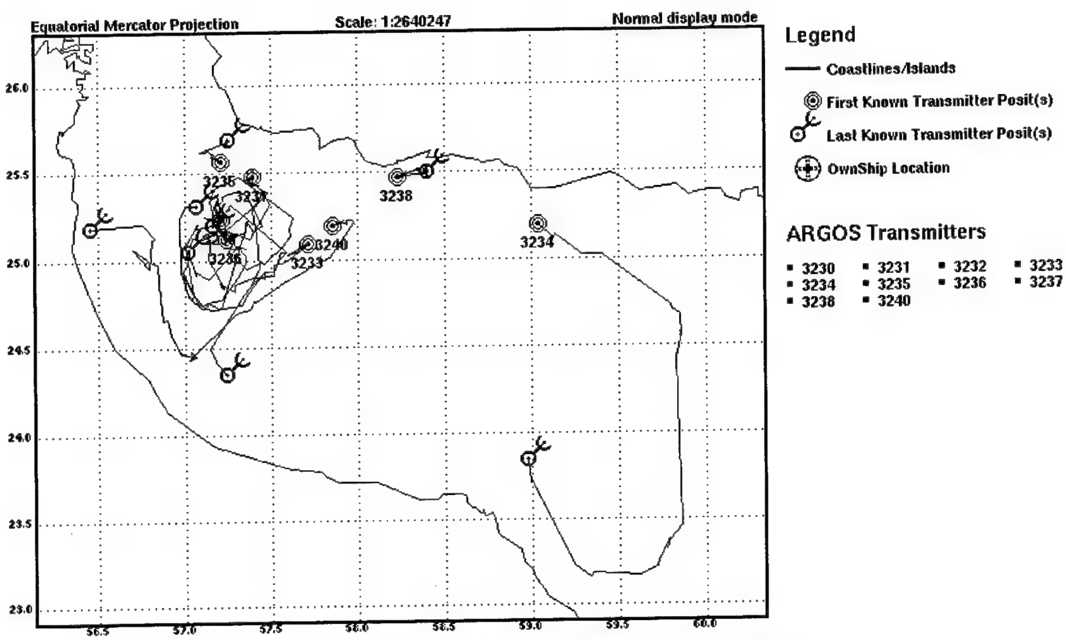


Fig. 5 — Geographic Plot of SHAREM 110 XAN-2 buoys

In June 1996, two AN/WSQ-6 XAN-2 ANS buoys and one XAN-4 Tz/ANS buoy were deployed to provide acoustic data to ASW and USW operations during SHAREM 117, conducted in the northern

Ionian Sea between Italy and Greece. The buoys were carried on station by P-3 aircraft several days in advance of comex and were deployed by embarked NAVOCEANO survey personnel. METOC and ambient noise data from the buoys were processed by SHAREM METOC forecasters at the Naval European METOC Center (NEMOC) in Rota, Spain. Fresh in-situ buoy data were collected using both the TESS-3/SMQ-11 system at the detachment (NEMOD) in Naples, Italy, and a VHF LUT installed at NEMOD Sigonella, Sicily. Buoy data were digitally transferred to the LOCUTUS-capable TRWS at NEMOC via the DoD secret internet protocol network (SIPRNET) link, with data transfer times consistently less than 5 seconds. The buoy data were then entered into the TEDS database every 3 hours The forecasting module in the shipboard tactical forecasting capability (STAFC) on the TRWS then employed the buoy data along with on-station METOC data from radiosondes and bathythermographs (BTs) to provide correction calculations to the gridded STAFC METOC fields, whose initial data are derived from satellite remote sensing and mathematical modeling. The reanalyzed STAFC fields were transmitted to the embarked METOC officer on the SHAREM 117 flagship for use in daily METOC, ASW, and USW evaluations. The buoy, sonde, and BT data provided critical regional correction to the STAFC meteorological fields, ensuring accuracy based on the latest METOC measurement technology. Figure 6 shows buoys deployed in SHAREM 117. Figure 7 presents sample ambient noise data showing tactically significant spikes correlating with sonar pinging during *go active* periods of the exercise.

LOCUTUS versatility was further demonstrated by its employment in three mutually connected locations during SHAREM 117. Its display capabilities were showcased at NEMOC where the ASW watchstander could view and perform quality control on METOC buoy data before entering it into TEDS to use in correction of STAFC METOC fields. The employment of the VHF LUT at NEMOD Sigonella assured data continuity during a 30-hour period when all S-band data transmission from the TIROS satellite was interrupted. The VHF LUT continued to receive DCS buoy data throughout the down period, and the LUT operator was able to continue 3-hour data delivery to the NEMOC ASW watchstander.

HURRICANE HUNT 1995

During the height of the 1995 Atlantic hurricane season, LOCUTUS was used to collect and display METOC buoy data during the passage of Hurricanes LUIS and MARILYN. On 8 and 18 September, a total of 17 METOC drifting data buoys were deployed across the track of Hurricanes LUIS and MARILYN by members of the U.S. Air Force 53rd Air Reconnaissance Squadron in the Northwest Atlantic Ocean between Charleston, South Carolina, and the island of Bermuda. Members of the LOCUTUS team coordinated data download and interpretation efforts with the following agencies: National Hurricane Center (NHC-NOAA, Miami, Florida), 53rd Weather Reconnaissance Squadron (Keesler AFB, Biloxi, Mississippi), Atlantic Oceanographic and Meteorological Laboratories (AOML-NOAA, Key Biscayne, Florida), the National Data Buoy Center (NOAA, Stennis Space Center, Mississippi), and the National Meteorological Center (NMC, Washington, DC). NHC forecasters were assisted with buoy data download using the local HRPT satellite receiving system loaded with LOCUTUS software. NHC forecasters actively used buoy data to modify and update several local weather forecasts for Bermuda and adjoining waters. Raw and tailored buoy data products were provided to the AOML senior hurricane scientist for reconstruction of storm track and area METOC evaluation.

Buoy data were collected mainly from the GLOBAL Imaging, Inc. HIPS S-band satellite receiver system on line at NHC. LOCUTUS software was loaded onto the HP-750 workstation front-end of the

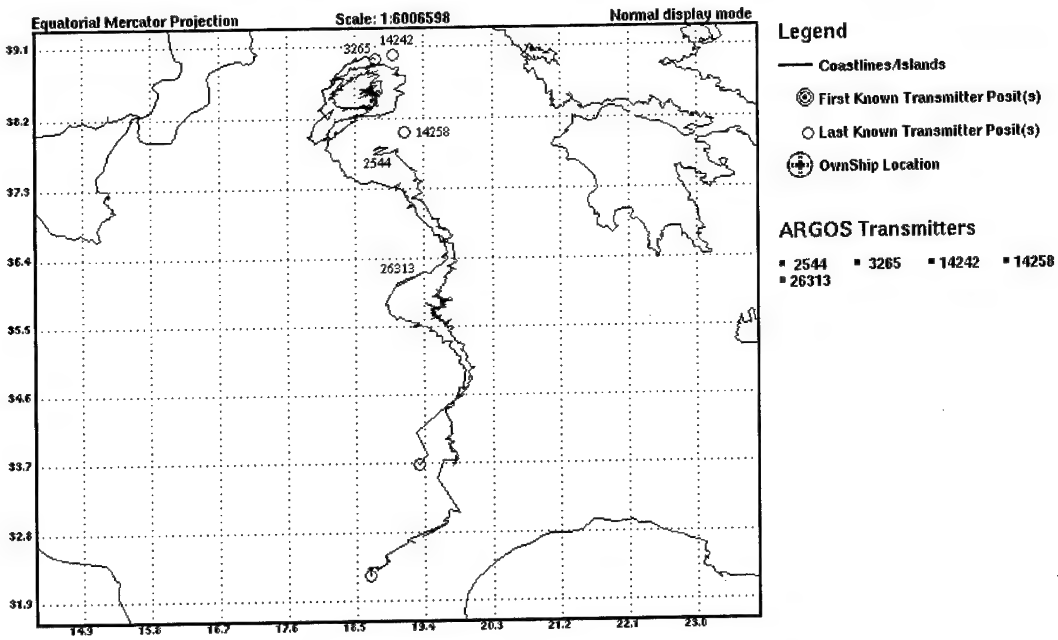


Fig. 6 — Geographic plot of SHAREM 117 buoys

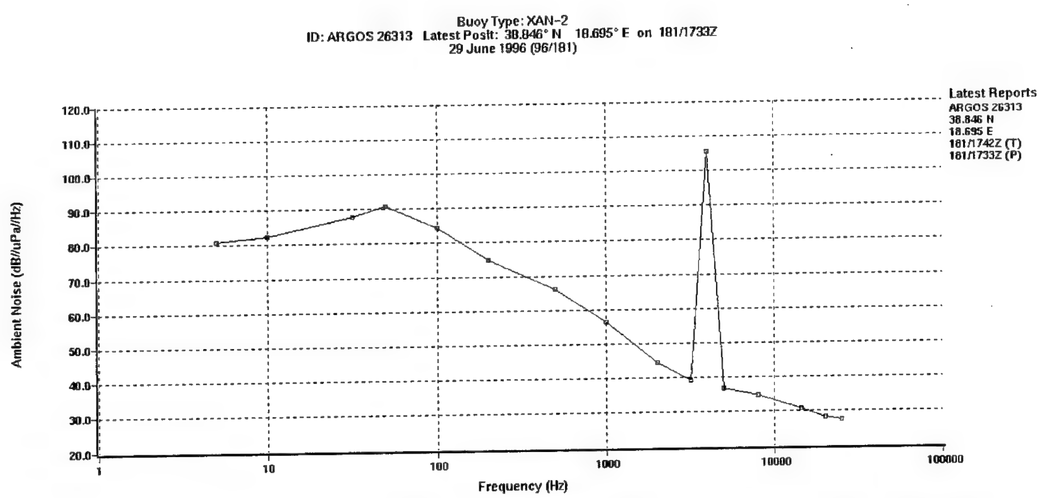


Fig. 7 — Ambient noise data from AN/WSQ-6 hydrophone drifting buoy deployed during SHAREM 117 showing probable effects of nearby active sonar activity

HIPS system in early July. An NRL RPTT was also installed on the NHC roof to assist with buoy position fixing. With the help of GLOBAL Imaging personnel on site at NHC, the TIP-file decoder of the LOCUTUS software was modified and custom tailored to accept the TIP-file format produced by the HIPS antenna system. At the time of arrival of the two hurricanes, the LOCUTUS module on the HIPS system was running fully automatically. Backup TIP data were also received at Stennis Space Center, Mississippi, using the T-RIS S-band satellite receiver system and the GAC-1A taped TIROS feed, both located at NAVOCEANO and both using LOCUTUS software for drifting buoy data display and archiving.

The experiment entitled Air-Drop Deployment of Buoys in the Path of a Tropical Cyclone was sponsored by the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) and originally expected to take place during the 1994 east coast hurricane season [9]. When no major west Atlantic or Gulf of Mexico hurricanes materialized in 1994, and after several false starts, the experiment was postponed for the 1995 hurricane season. Finally, September Hurricanes LUIS and MARILYN exhibited a favorable trajectory between the United States east coast and the island of Bermuda. Seven NRL CMOD buoys and three NOAA wind-speed-and-direction (WSD) buoys were deployed in a line extending from the continental slope near Charleston, South Carolina, to a point about a hundred miles west of Bermuda. The buoy deployment was made by airmen of the 53rd Air Reconnaissance Wing from Keesler Air Force Base in Biloxi, Mississippi, the *Hurricane Hunters*. The buoy line was dropped about 150 nautical miles from the center of Hurricane LUIS, at a point where forecasters at the NHC believed that its track would continue relatively straight and fast. Figure 8 is a LOCUTUS graphic showing the geography of the buoy deployment and the storm track. Figure 9 is another LOCUTUS graphic displaying temporal meteorological data from a NOAA WSD buoy. Note the winds backing in direction and swelling in intensity with passage of the storm. Most of the buoys stayed on the air for weeks after the passage of hurricane LUIS, allowing the bonus of buoy coverage for hurricane MARILYN, which ran over the buoys 10 days later on roughly the same track as hurricane LUIS. A further four AN/WSQ-6 and three WSD buoys were deployed for MARILYN on 18 September 1995, of which six remained on the air long enough to contribute METOC data when overrun by the storm. The Hurricane Hunt '95 project was the largest and most successful demonstration to date of real-time reception of drifting buoy METOC data using exclusively government-owned *footprint* METOC satellite receiving systems.

GUAM TYPHOON BUOY DATA

Meteorological data from several AN/WSQ-6 CMOD buoys in the southwest Pacific Ocean include dramatic in-situ data from a typhoon passing over the buoys' positions. Figure 10 shows the geographic location of several buoys and the track of Typhoon ORCHID. Figure 11 shows surface atmospheric pressure data as Typhoon ORCHID passed just east of the buoys in October 1994. Note the sharp plunge in pressure as the storm center approached each buoy and the equally sharp pressure recovery as the typhoon passed and continued on a northward track. These buoys had been deployed for long-term climatological research and were in the path of the storm by coincidence. The data illustrate the buoys' potential as typhoon or hurricane forecasting aids. The data were collected directly from the VHF LUT located at the Naval Pacific METOC Center/Joint Typhoon Warning Center in Guam. In addition to on-scene LOCUTUS reception and monitoring, these data were able to be observed and monitored via an Internet connection on a LOCUTUS-capable computer at NRL Stennis Space Center, Mississippi.

GULF OF MEXICO INSHORE CIRCULATION EXPERIMENT

In April 1995, 13 AN/WSQ-6 XAN-3 drifting buoys with 120-m thermistor (Tz) tails and 5 AN/WSQ-6 XAN-1 CMOD buoys with 4-m drogues were deployed in the northwestern Gulf of Mexico by small commercial aircraft as part of a study of shelf and slope watermass circulation. The effort was conducted as a part of the Global Ocean Monitoring and Prediction (GOMAP) project sponsored by the Strategic Environmental Research and Development Program (SERDP), using personnel and resources

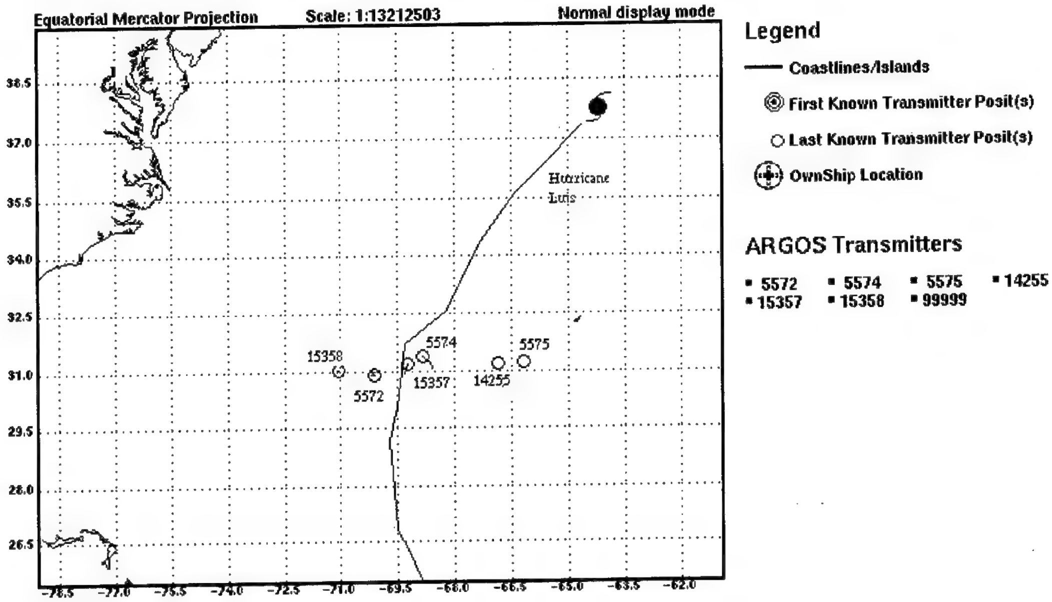


Fig. 8 — Geographic plot of buoys and the track of Hurricane LUIS

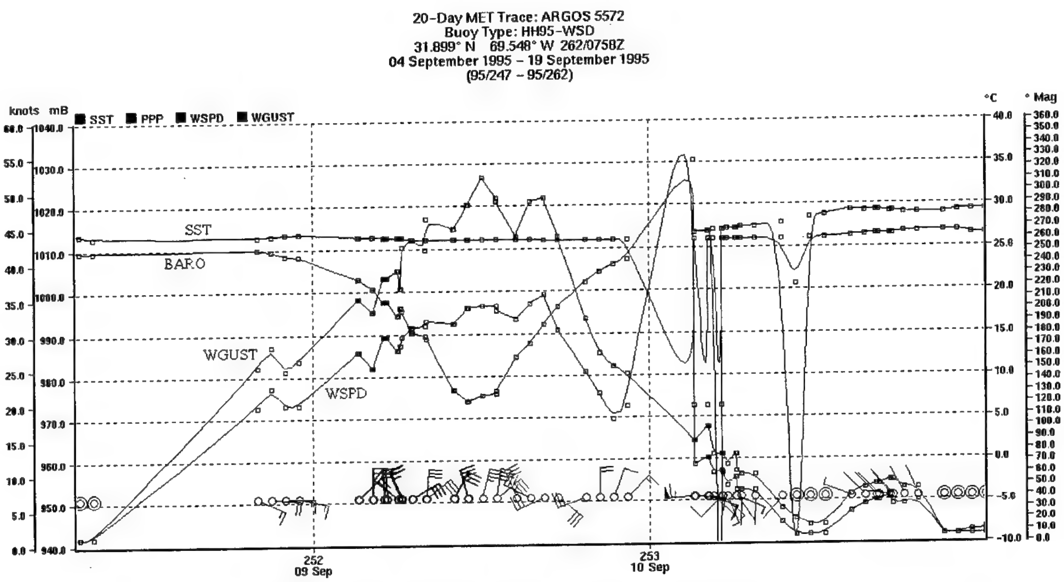


Fig. 9 — Meteorological data collected in Hurricane LUIS

from the NRL Ocean Modeling and Prediction Branch, the LOCUTUS team, and the TOWS program office. The chief GOMAP objectives addressed by this study were improvement of long-term watermass observation techniques plus design and simulation of local or regional watermass environments. The CMOD buoys were deployed to the upstream portion of the continental shelf. The Tz buoys were deployed to provide coverage over the continental slope. Infrared imagery was added to reveal ocean thermal features like loop current eddies and watermass fronts. Nearly 800 buoy-days of METOC buoy

25 September 1994 - 06 October 1994
(J.D. 268-279)

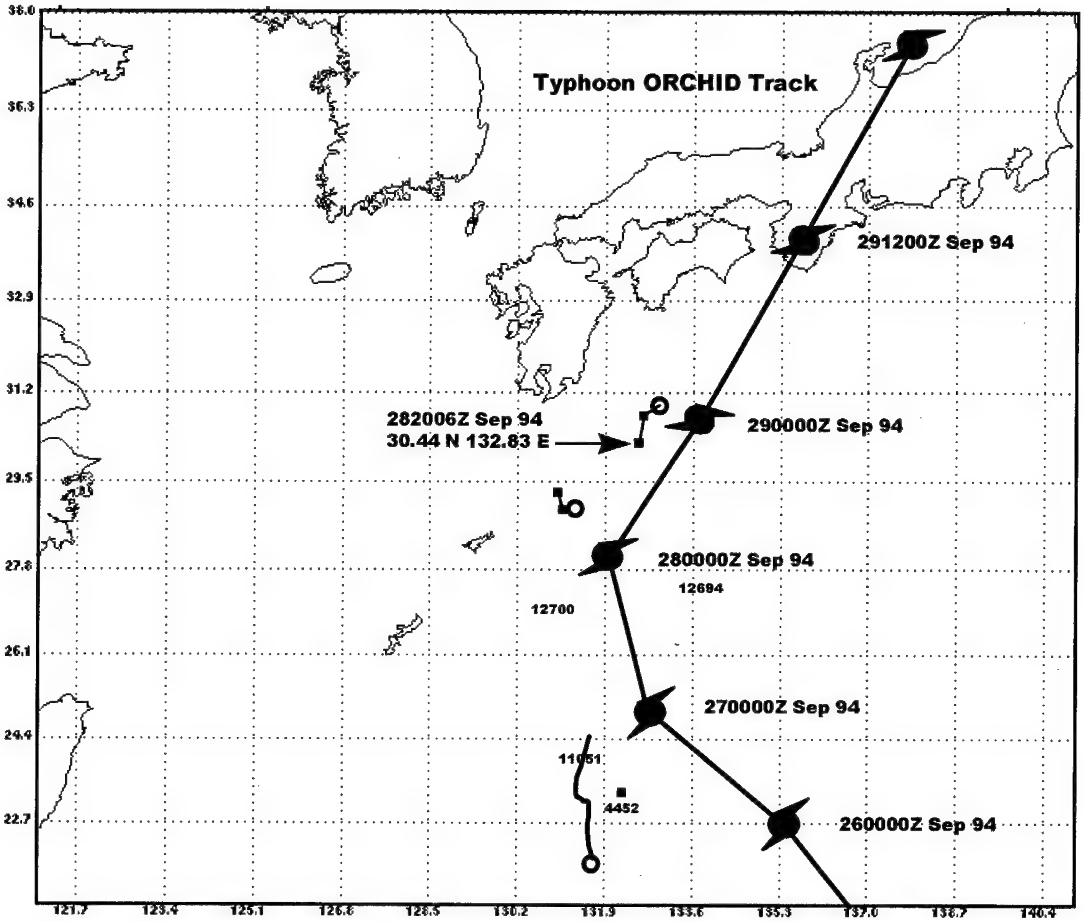


Fig. 10 — Geographic plot of Typhoon ORCHID

observations were collected using LOCUTUS drifting buoy data display software and the TELONICS T-RIS HRPT satellite receiver system at NAVOCEANO, with backup data coming from the GAC-1A DOMSAT system. The GOMAP buoy trajectories shown in Fig. 12 indicate complex shelf-slope current and watermass exchange. The data collection contributed to the development of initialization and boundary conditions for shelf circulation models and to the verification of larger scale simulations. Measurements from the Tz buoys were used to construct a time series of temperature profiles along the shelf edge such as those depicted in Fig. 13. The results provided insight into the spatial and temporal variability of watermass circulation over the Louisiana-Texas shelf and slope.

RECOMMENDATIONS FOR FUTURE SYSTEM IMPROVEMENT

The incorporation of LOCUTUS software into METOC SAT receiver systems has dramatically improved the Navy's ability to receive and process METOC buoy data in real time. With major combatant ship testing of LOCUTUS in the fall of 1996, this capability will soon be available fleet wide at sea. LOCUTUS software and vastly improved METOC SAT receiver systems have stretched the

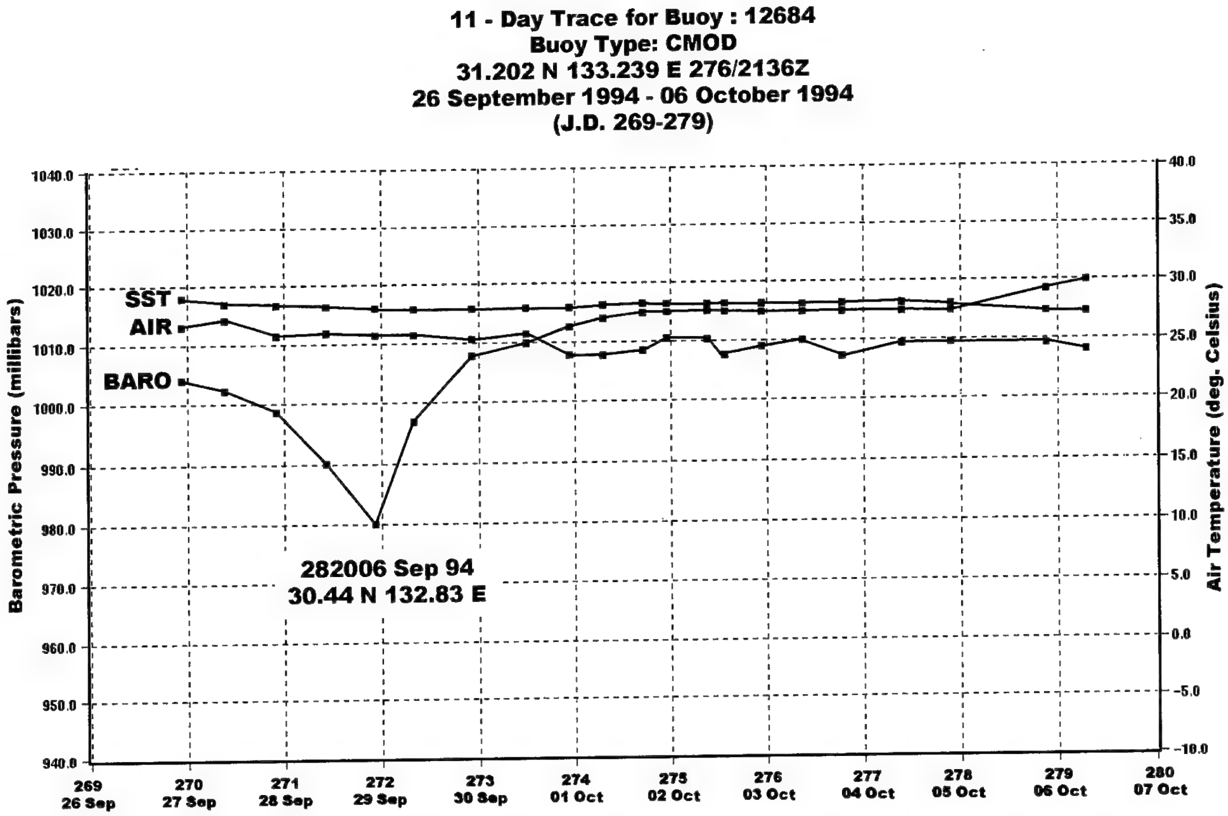
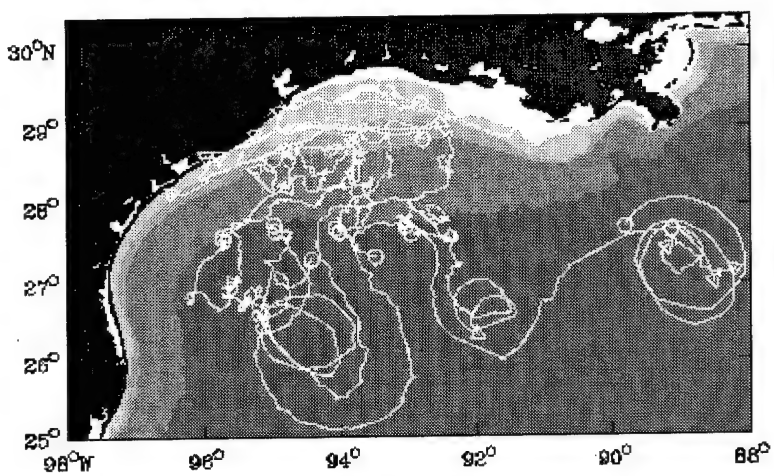


Fig. 11 — Meteorological data collected from Typhoon ORCHID



1995 GOMAP Drifter Trajectories
11,20,300, 200 m isobaths

Fig. 12 — Geographic plot of GOMAP buoys

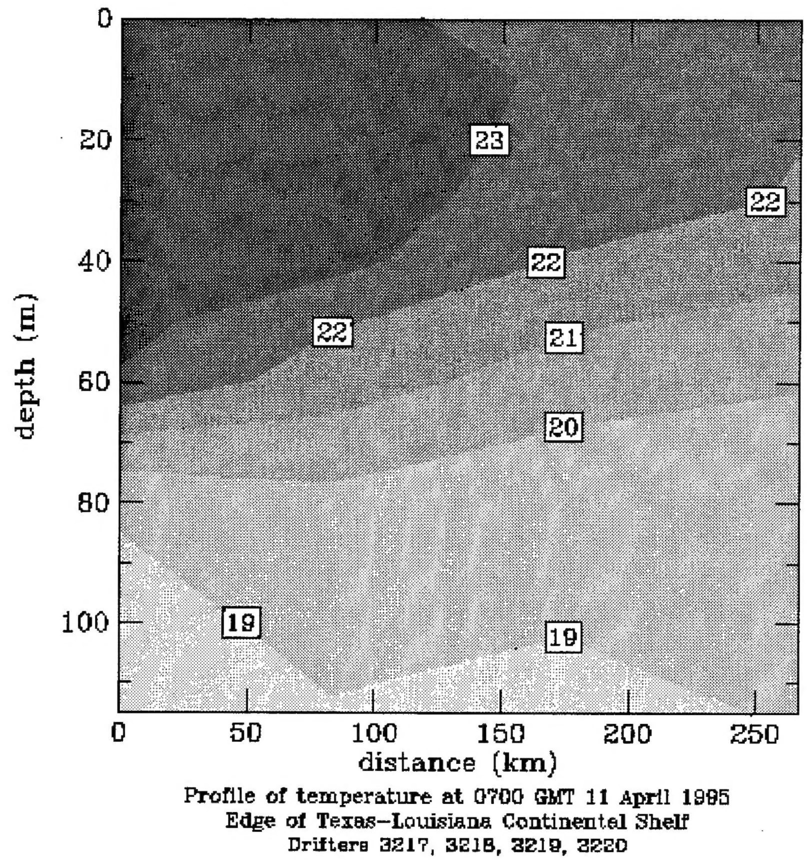


Fig. 13 — Plot of GOMAP current structure from buoy data

TIROS-DCS data relay system to its design limits. With virtually no limit on data storage capacity and LOCUTUS data processing capability, the Navy is ready for the next generation of buoy data relay technology. The AN/WSQ-6 drifting buoy, the LOCUTUS software module, and the TESS-3/SMQ-11 METOC SAT receiver system are all ready with nominal modification to accommodate a fully continuous, worldwide satellite relay system for in-situ METOC data transmission.

A system is conceived where METOC buoys, radiosondes, AWOS units, and experimental devices are deployed in great numbers in tactically, strategically, and climatologically significant areas. This system would employ burst communication through a worldwide, total-coverage satellite constellation (the ORBCOMM and IRIDIUM systems come to mind) and METOC SAT receive capability already available. Thousands, and perhaps hundreds of thousands, of METOC measurement devices, made affordable through miniaturization, could be deployed and not even begin to saturate or overload system hardware and software components. Two-way communications between buoy and receiving station could be accomplished using existing equipment and software with minor modification. The prolonged *data holiday* periods of nonreception associated with the polar orbiting TIROS satellite would be avoided. The installation of GPS on all METOC devices would eliminate the obsolete practice of positioning via range-rate calculation. The vast in-situ data delivery of the new system would fill in myriad geographic holes in naval METOC databases and provide the robust quantities of initialization data with which the sophisticated Navy METOC and acoustic models were meant to operate. Finally, the new system, completely domestic in manufacture and operation, would be designed with faster data rates and tight

security features impossible with the current come-one come-all operation inherent in the TIROS-DCS data relay system. LOCUTUS is ready now.

ACKNOWLEDGMENTS

The following individuals were instrumental to the success of the Drifting Buoy Engineering Enhancement Project and the development of LOCUTUS. Our warmest thanks go to each them. Many other dedicated professionals too numerous to include in this list were also of great help and receive our implicit thanks.

Harry Selsor, Ken Ferer, Frances Bang; Naval Research Laboratory Tactical Oceanography Warfare Support Program Office, Stennis Space Center, Miss.
John Ellis, Jim Matthews, Paul Bucca, Ron Picard; Acoustic Simulation and Tactics Branch, Naval Research Laboratory, Stennis Space Center, Miss.
Larry Phegley, Rosemary Lande, Ted Tsui, Kim Richardson; Tactical Systems Section, Naval Research Laboratory, Monterey, Calif.
Mark Fernandez; Planning Systems, Inc., Bay St. Louis, Miss.
Dave Salzburger, Harlin Adams, Martial Car, Elizabeth Horton, John Brown, Burr Loomis: Naval Oceanographic Office, Stennis Space Center, Miss.
Brian Ackerman, Dale Hoit, Marc Amshoff; Naval Air Warfare Center, Aircraft Division, Indianapolis, Ind.
CDR Dave Markham, David Minton, CDR Hank Pomeranz; SPAWAR PMW185
Charlie Barron; Ocean Dynamics and Prediction Branch, Naval Research Laboratory, Stennis Space Center, Miss.
Mickey Thiele, Ken McDaniel, Francis Grosz; Oceanography Division, Naval Research Laboratory, Stennis Space Center, Miss.
Pete Black; Atlantic Oceanographic and Meteorological Laboratory, NOAA, Key Biscayne, Fla.
Steve Baig, Salim Leyva, Ed Rappaport; National Hurricane Center, NOAA, Miami, Fla.
MSGT Robert E. Lee, MAJ Robert Katz, USAF, 53rd Weather Reconnaissance Squadron, Keesler Air Force Base, Biloxi, Miss.
Mike Burdette, Eric Meindl, LCDR Neil Van De Voorde; National Data Buoy Center, NOAA, Stennis Space Center, Miss.
Marshall Earle; Neptune Sciences, Inc., Reston, Va.
Charlie Hoisington; Science Systems and Applications, Inc., Lanham, Md.

REFERENCES

[1] *Service ARGOS Users Manual*, Vol. 3., p. 8, Service ARGOS, Inc., Landover, MD, 1986.

[2] "Performance Specification for the NOAA-K, L, M, N, N-prime Satellites," Publication GSFC S-480-25.1 Attachment 6, Goddard Space Flight Center, Greenbelt, Md., 1986.

[3] Selsor, Harry D., "Data From the Sea: Navy Drifting Buoy Program," Sea Technology, **34**(12), 53-58 (Dec. 1993).

[4] TIROS Spacecraft Data Collection System Transmitter Location Program: Bangladesh Agro-climatic Environmental Monitoring Project, Science Systems and Applications, Inc. Lanham, Md., 1984.

[5] Edward B. Arthur, "Satellite Data Receiving and Processing System," The NORDA Review, Naval Ocean Research and Development Activity (now NRL), Stennis Space Center, Miss., March 1986.

[6] "Data Extraction and Calibration of TIROS-N/NOAA Radiometers," NOAA Technical Memorandum NESS 107, Rev. 1, pp. 15-30, (Oct. 1988).

[7] "The TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS 95, 5-15, 40-76, 1982.

[8] D. Sallis, "Software Design Document for the Drifting Buoy Data Display Program (LOCUTUS 2.0)," Analysis and Technology, Inc., Bay St. Louis, Miss., Feb. 1995.

[9] "Draft Test Plan for Air-Drop Deployment of Buoys in the Path of a Tropical Cyclone," Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), Rockville, Md., June 1994 .

ACRONYM LIST

ASW	antisubmarine warfare
AOML	Atlantic Oceanographic and Meteorological Laboratories
AUTODIN	Automatic Digital Network
AWOS	Automated Weather Observation Station
BTs	bathythermographs
CDA	Command and Data Acquisition
CMOD	compact meteorological and oceanographic drifter
CNES	Le Centre National D'Etudes Spatiales
CNMOC	Commander, Naval Meteorology and Oceanography Command
COMEX	commencement of exercise
COTS	commercial-off-the-shelf
DCS	data collection system
DOMSAT	Domestic Communications Satellite
DSB	double sideband
GAC	global area coverage
GOMAP	Global Ocean Monitoring and Prediction
GTS	Global Telecommunications Service
GUI	graphical user interface
HIPS	HRPT Image Processing System
HRPT	high resolution picture transmission
LAC	local area coverage
LUT	local user terminal
LOCUTUS	LUT Upgrade System
METOC	Meteorology and Oceanographic Command
NAVICEN	Naval Ice Center
NAVOCEANO	Naval Oceanographic Office
NAVOCEANO WSC	NAVOCEANO Warfighting Support Center
NDBC	National Data Buoy Center
NEMOC	Naval European METOC Center
NEMOD	Naval European METOC Detachment

NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
OPAREA	operating area
OTCIXS	Officer in Tactical Command Information Exchange System
OTG	over-the-horizon-targeting GOLD
PTT	platform transmit terminals
RPTT	reference platform transmitter terminals
SDRPS	Satellite Data Receiving and Processing System
SERDP	Strategic Environmental Research and Development Program
SHAREM	Shipboard Antisubmarine Warfare Readiness and Effectiveness Measurement Exercises
SHF	super high frequency
SIPRNET	secret internet protocol network
SPAWAR	Space and Naval Warfare Systems Command
SPS	standard positioning service
SSAI	Science Systems and Applications, Inc.
STAFC	shipboard tactical forecasting capability
TEDS	Tactical Environmental Database Subsystem
TESS	Tactical Environmental Support System
TIP	TIROS information package
TOWS	Tactical Oceanographic Warfare Support
TRWS	TESS remote workstation
Tz	thermistor
USW	undersea warfare
WMO	World Meteorological Organization
WSD	wind, speed, and direction